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THE BURR--MANUFACTURING'S PERENNIAL THORN

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THE BENDIX CORPORATION

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THE BURR - MANUFACTURING'S
PERENNIAL THORN

Burrs

Burr Prevention

Burr Minimization

Product Design

Deburring

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Abstract

There are five approaches to minimizing deburring costs. Improvements in deburring processes represents the most common approach. The four approaches which are often overlooked include value analyzing product requirements, practicing burr prevention and minimization, and removing burrs during idle time. Examples of each approach are described.

THE BURR - MANUFACTURING'S PERENNIAL THORN

When Eli Whitney contracted to produce 10,000 muskets in 1798 he introduced two major manufacturing concepts familiar to each of us:

- The concept of mass production
- The concept of an unending pile of parts waiting for hand deburring

Through the persistent and innovative efforts of thousands since that time mass production concepts have evolved to a level that even today's public cannot always grasp. Yet if Eli Whitney walked in the door of most manufacturing plants today there is one area he would instantly recognize - the "burr benches."

Those involved in manufacturing know one all too obvious fact - burrs presently cost us a large sum of money. Manufacturers in the United States annually spend over one billion dollars to remove burrs and radius edges on machined components. This represents roughly $2\frac{1}{2}\%$ of the cost of component parts. If detailed cost figures were available the actual cost to consumers would probably be much higher. Hidden costs associated with part rejections or failures due to burrs can be very expensive. Rework to completely remove burrs, reinspection and the associated paperwork seldom appear in the deburring charges. The fact that many machine operators deburr parts while their machine is cycling on another part is considered good practice by most companies. But the fact is if that operator weren't deburring he could be doing something else to reduce costs. This deburring is not free if the operator could be otherwise improving quality or reducing costs. This is another hidden deburring cost. The cost of inefficiency and morale due to hands cut and sore from hidden burrs is also very difficult to ascertain.

Unfortunately when most individuals hear the word burr they immediately associate it with deburring. Those who have looked at deburring in depth recognize that nothing in product design or function dictates a burr removal process. Even when deburring is used several approaches can reduce these costs.

A value engineering study of burrs and deburring reveals five distinct areas of potential cost savings:

- 1) Product Design
- 2) Burr Prevention
- 3) Burr Minimization
- 4) Burr Removal During Idle Time
- 5) Burr Removal Processes

Cost reductions associated with product design fall into two categories:

- 1) Design of components to eliminate or minimize the need for deburring
- 2) Understanding component function and actual deburring requirements

Some components and assemblies can obviously operate adequately without deburring. The mechanisms in many children's moving toys for example need not be deburred. Sheet metal edges are often more aesthetic and trouble free if a rolled edge is produced. In this case deburring is not required on the hidden edge. Both of these examples are a direct result of design requirements. In the first case the designer somehow had to specify that edges could have burrs. In the second case the designer utilized the geometry of the part to reduce deburring. The majority of assemblies may not lend themselves to such obvious design changes. The point is, however, that if deburring can be eliminated from even one part in an assembly there is a consequent cost savings. Two common examples in which burr removal is not required are shown in Figures 1 and 2. Pins which are pressed into a hole often do not have to be entirely burr free. In Figure 2b the part was machined so that the burr was thrown into the shoulder relief. Since the burr does not interfere with part function and cannot escape from the relief, deburring is not required.

Probably the one area capable of the largest cost savings is that of understanding what edge requirements actually are. Although the product engineer is theoretically responsible for product definition, historically the manufacturing or quality engineers have assumed responsibility or indicating what is really required in the area of surface finishing. In the rush to get new products into production actual requirements are often glossed over. The essential aspect in this phase is to be able to answer the following question affirmatively.

"DO YOU KNOW WHAT LEVEL OF QUALITY IS NEEDED?"

Actually answering this question opens a Pandora's box of subsequent questions. Firstly to answer the question affirmatively requires a knowledge of the component's and assembly's function. Then one needs to know just how critical each edge is to the function of the component and assembly. Most individuals assume without thinking that all edges should have the same edge radius or burr free condition. In most situations this is not true. Another consideration at this point concerns in-process deburring. Even though some burrs may be removed in a subsequent machining operation, fixturing or inspection requirements may dictate that these burrs be removed. In this situation the deburring quality level is not as critical as the final functional requirement. Some of the questions the product and manufacturing engineers must answer in this evaluation are:

IS A BURR ALLOWABLE?

- Would it cause an electrical short circuit?
- Would it jam a mechanism?
- Would it cause interference fits?
- Would it cause misalignment?
- Would it be a safety hazard? (Would it cut someone's finger during assembly)
- Would it cause unallowable stress concentrations?
- Would it accelerate wear beyond allowable limits?

The manufacturing engineer must also be able to answer the following questions.

- Why is burr free condition required?
- Why is ___ max. edge radii required?
- Where is burr free condition required?
- Where is ___ max. edge radii required?
- How is burr free condition measured?
- How is edge break condition measured?
- What happens if part is not burr free?
- What happens if part does not have ___ max. edge radii?
- How can part be redesigned to minimize the burr?

By some means the production operators also must be informed of the actual quality required on all edges. In some cases this can be controlled by the choice of deburring technique. On many parts, however, the engineer must designate not only the quality required but the edges which must be deburred at a given operation. In some cases an illustration such as Figure 3 is adequate. Each edge to be deburred is marked by a check mark. In other cases a code such as shown in Figure 4 is required. The following table lists some additional ways of specifying allowable burrs and edge quality.

METHODS OF DEFINING AN ALLOWABLE BURR OR EDGE CONDITION

- Define it on the print.
- Define it in a Process Engineering Specification (Manufacturing Specification)
- Define it on the production traveler (routing sheets)
- Define it by interpretive memo. Such a memo could include sketches, photos, measuring techniques, etc.
- Define it on the inspection traveler.
- Define it with photos of acceptable and unacceptable conditions.
- Define it by the use of comparative masters (the master is given a tool or gage number, or a visual aid or visual standard number).
- Define it by go-no go. If it fits the gage, the burr is acceptable.
- Define it by taking specific exception to general workmanship specifications.
- Define it by special specifications.
- Define it by such phrases as "Firmly adhered burrs or raised metal is allowable in this area provided a micro tool 90° hook will not dislodge them"

If burrs can be prevented from forming then deburring would not be required.

Unfortunately altering speeds, feeds, and tool geometries will not prevent

burrs. Both analytical and empirical studies [1,2,3] have shown that while tool sharpness and cutting conditions can minimize burr size and control burr repeatability, they cannot prevent burrs. Conventional machining techniques always produce burrs. Theoretically, supporting the workpiece with a piece of backup material should prevent burrs. From a practical standpoint, however, backup material only helps to minimize burrs.

This can be seen by looking closely at a workpiece. Most operations produce burrs at more than one location. In drilling for example, one obtains a burr at both hole entrance and hole exit. In a milling operation burrs can be produced on up to ten edges. Thus at best one minimizes only burrs on one side of the workpiece.* While minimizing burr size is a distinct advantage it is not as desirable as burr prevention.

Burrs can be prevented by employing some of the non-traditional processes. As seen in Table 1 most of the non-traditional processes do not produce burrs. Despite many statements to the contrary EDM, EBM and Laser Machining (LBM) do

*Theoretically it would be possible to completely cover a part with "backup" material and prevent all burrs. From a practical standpoint this is not very realistic because the "backup" material must have the same properties as the workpiece to prevent burr formation.

TABLE 1
Non-Traditional Machining Capabilities

Process	Typically Makes Burr?'	Typical Edge Radius Produced (inch)	Typical Machining Tolerance
AJM	No	0.003	
CHM	No	Unknown	± .002
EBM	Yes	-	± .001
ECDM	Unknown	Unknown	Unknown
ECG	No	0.003	± 0.002
ECM	No	0.001	± 0.002
ECH	No	0.0005	± 0.0002
EDM	Yes	-	± 0.0006
ELP	No	0.001	± 0.0005
ESM	No	0.002	± 0.001
HCG	No	0.002	± 0.003
IBM	No	0.00005	± 0.0001
LBM	Yes	-	± 0.001
PAM	Yes	-	± 0.003
USM	No	0.001	± 0.001
WJM	No	Unknown	± 0.003

'Where burr is visible under 30X magnification.

ELP = Electrolytic polishing = electropolishing
WJM = Water Jet Machining
HCG = Hot chlorine gas machining
ECH = Electrolytic honing
ECDM = Electrochemical Discharge Machining
ESM = Electrostream machining

produce burrs.* While little test data is available on edge quality produced, two sources provide some insight. McBride's study [4] documents the effects of EDM parameters on EDM burr size, and the book Non-Traditional Machining Processes [5] discusses the edge conditions produced by EBM and LBM. Recent research on LBM, however, indicates that when a high velocity air blast is synchronized with the laser the majority of the burr is blown out before it can solidify on the workpiece. Thus in the future LBM may fall in the category of a non-burr producing process.

*These burrs are recast material rather than the traditional burr. From a practical standpoint the author defines a burr as material which was not at the indicated edge prior to machining (or pressworking) and which is not desired at that position.

Whenever possible processes such as CHM, ECG, ECM, ECH, ELP, and ESM should be utilized. They not only eliminate deburring costs but they provide excellent surface finishes and minimize welding, brazing and plating problems caused by media impregnation or improper cleaning. In addition the elimination of unnecessary operations reduces paperwork costs and shortens production flow time.

The disadvantages of using the non-traditional processes include high equipment costs, limitations to certain geometries and workpiece materials, and workpiece tolerance and surface integrity problems. These factors are discussed in detail in [5] .

While burr prevention may not be feasible in many situations burr minimization is always feasible. Actually burr minimization encompasses two distinct areas.

- 1) Physically limiting burr size and toughness and
- 2) Making the burr easy to remove

It is a commonly known fact that small burrs are easier to remove than large burrs. Few people today, however, can quantitatively describe how machining conditions affect burr size. As a result industry has never tried analytically to determine conditions which give minimum manufacturing costs. The majority of industry minimizes machining costs rather than the sum of machining plus deburring costs. As a result some products are not produced at their most economical cost. Figure 5 is a conceptual illustration of how feedrate affects total piece part unit cost.* While point A is the feedrate generating minimum machining costs it results in a higher total unit cost than does feed rate B. While calculating the total cost may not be required for many commercial products, it

*Total as used here includes both deburring and machining costs for a specific operation.

certainly should be considered for many of the precision aerospace components. While the author knows of no published data illustrating deburring costs as a function of machining conditions such data is being generated.

Burr minimization requires a quantitative knowledge of how burrs vary with machining variables. Minimum cost deburring also requires a knowledge of how deburring costs vary with burr properties. Current research by several companies should provide a reasonable data base for determining burr properties as a function of machining conditions. While burr length has been measured for some time [6-9] it has only been recently that studies have included the more significant properties of burr thickness and toughness [1-3] .

Within the next two to three years literature will appear on the following subjects.

- Physical phenomena of burr formation
- Burr properties as function of tool wear
- The production of consistent or repeatable burrs
- Economic trade-offs between machining and deburring

Several general rules are now known, however,

- Sharp tools minimize all burr properties
- Workhardening materials produce thicker burrs than non-workhardening materials
- Burr hardness is higher than the parent material hardness for work hardening material
- Supporting the machined edges minimizes burr size
- High feedrates typically (but not always) produce thick burrs

Table 2 illustrates the differences in burr properties produced by sharp and dull cutters. If a choice is available in materials choose a non-workhardening material to minimize burr thickness and the hardness differential between the burr and workpiece. While the last rule in the above list is universally known the actual economics of this approach are often ignored. Several companies have found that "burr" type cutters such as Metal Removal Company's "Master Cut" greatly reduce the burr thickness and length produced in milling operations.

As indicated previously burr minimization in its broadest interpretation includes more than just minimizing burr size. It involves more than a knowledge of how all variables affect a given operation. It includes other approaches to making the burr easy to handle.

Making the burr easy to remove involves two aspects:

- Locating the burr in the best position
- Controlling burr size by appropriate selection of machining sequences

Figure 6 provides an excellent example of burr placement. The cutoff burr in the right hand view is masked by the large diameter of the part. In the left hand view the burr is exposed to the action of vibratory deburring and can be readily removed provided tolerances are adequate. Figure 7 is another example of burr placement. Production routing sheets should indicate where the cutter exit burr should be. In this case a burr at the step in diameter would double the time required to deburr this part.

Correct burr placement can pay big dividends on milled parts because of the large number of edges produced. On intersecting features placing the burr on the most accessible edge can reduce burr costs by 50%. The correct placement of burrs can change a normally hand deburr situation to a much more economical and repeatable vibratory deburr operation. In some operations burr placement can be controlled by a simple tape change. In some cases climb milling rather than conventional milling will provide better location. Since tooling may be involved it is important to consider burr placement in the preliminary processing steps.

TABLE 2
COMPARATIVE BURR SIZES

CONDITION	BURR WIDTH	HARDNESS		INITIAL BURR LENGTH
		PARENT	BURR	
		ALUMINUM WORKPIECE		
ABUSIVE FACE MILLING (MAXIMUM BURR)	$\bar{w} = 0.0078$ $\sigma = 0.0011$	$\bar{h} = 115$ $\sigma = 4$	129 9	$\bar{L} = 0.0138$ $\sigma = 0.0045$
GENTLE PROFILE MILLING (MAXIMUM BURR)	$\bar{w} = 0.0023$ $\sigma = 0.0003$			$\bar{L} = 0.0015$ $\sigma = 0.0010$
BERYLLIUM COPPER WORKPIECE				
ABUSIVE FACE MILLING (MAXIMUM BURR)	$\bar{w} = 0.0045$ $\sigma = 0.0008$	$\bar{h} = 249$ $\sigma = 7$	268 22	$\bar{L} = 0.0189$ $\sigma = 0.0017$
GENTLE PROFILE MILLING (MAXIMUM BURR)	$\bar{w} = 0.0007$ $\sigma = 0.0005$			$\bar{L} = 0.0016$ $\sigma = 0.0011$
1018 STEEL WORKPIECE				
ABUSIVE FACE MILLING (MAXIMUM BURR)	$\bar{w} = 0.0046$ $\sigma = 0.0010$	$\bar{h} = 230$ $\sigma = 7$	275 17	$\bar{L} = 0.0255$ $\sigma = 0.0191$
GENTLE PROFILE MILLING (MAXIMUM BURR)	$\bar{w} = 0.0014$ $\sigma = 0.0002$			$\bar{L} = 0.0024$ $\sigma = 0.0009$
STAINLESS STEEL WORKPIECE				
ABUSIVE FACE MILLING (303 SS) (MAXIMUM BURR)	$\bar{w} = 0.0049$ $\sigma = 0.0020$	$\bar{h} = 305$ $\sigma = 0$	428 56	$\bar{L} = 0.0095$ $\sigma = 0.0053$
GENTLE GRINDING (416 SS) (NOMINAL BURR)	$\bar{w} = 0.0013$			$\bar{L} = 0.007$

ABUSIVE FACE MILLING - BURR PRODUCED BY A DULL FACE MILL AND 0.025 INCH DEPTH OF CUT.

GENTLE PROFILE MILLING - BURR PRODUCED BY THE BOTTOM OF A NEW 4 FLUTE 1/4-INCH DIAMETER END MILL AT 2730 RPM AND 9 3/16 IPM

HARDNESS VALUES ARE KNOOP HARDNESS NUMBER WITH 100-GRAM LOAD (249 ~ Rc24, 115 ~ RB73).

$\bar{w}$ = average burr thickness

$\bar{h}$ = average burr hardness

$\bar{L}$ = average burr length (height)

σ = standard deviation

The decision of which machining sequence to use can affect deburring time. As an example the part in Figure 8 would typically be turned then the three flats would be milled. This creates two undesirable facets though. First milling typically makes a heavy burr and secondly deburring would require a separate operation. The company which produced this part chose to mill the flats before turning the stem diameter. This produced a smaller burr and allowed the operator to brush the burrs off with a wire brush as a part of the lathe operation.

When the manufacturing engineer considers the machining sequence he wants to follow he should consider the "burr" as significant a factor as the desired surface finish and tolerance. The following check list has been prepared to help in processing and in troubleshooting burrs:

ASK YOURSELF

1. Does the burr have to be removed?
2. Can the part be redesigned
for less machining
for less deburring
3. Will the burr be cut off in a later machining operation. If the machining sequence were changed would the burr be cut off?
4. Is the burr accessible?
Should I change the sequence of operations?
Should I change the direction of cut?
5. Can I choose a cutter that gives a smaller burr?
6. Do I know the feedrate which gives the smallest burr?
7. Can I use a subsequent heat treat to make the burr brittle?

8. Would a change in coolant or method of application make the burr brittle?
9. Does the burr have to be removed now?

Production operators can do a great deal to minimize burr removal costs. The most obvious item is to have them deburr parts while their machine is cycling on the next part. Even a partial deburr will save time in subsequent operations. Shops in which deburr operators and machine operators are in separate labor classifications should encourage machine operators to work with deburr operators in deciding when tools should be changed. Unfortunately in many shops the machine operator could care less about the burr he produces because he is not held accountable for the extra work required to remove gross burrs.

Some additional thoughts on in-process burring include:

SOME IN-PROCESS DEBURRING APPROACHES

1. • Remove heavy burrs only (leave small burrs if they have to be removed mechanized processes will remove them cheaper)
 - Provide operators with special design tools to remove heavy burrs.
Special knives, reamers, countersinks, or cutters can dramatically speed burr removal.
 - Machine off heavy burrs
Thick burrs can often be cut or ground off faster than an operator can remove them with a knife.
2. Deburr only as required for later fixturing.
Save the majority of deburring for the final operation. This reduces the time operators spend in scrutinizing edges which have already been deburred. Some burr laden edges may be cut off in later operations; thus complete in-process deburring would have added some unnecessary expense. If part is scrapped in a later machining operation deburring costs will not have been wasted.

3. Change burr location

Put the burr where it is easy to remove, or where it will not have to be removed (Figure 2).

4. Deburr on machine time

Provide deburr aids (pictures, samples of adequately deburred parts, special deburring tools).

Add deburr steps in the machining cycle.

Often an extra machining pass can be used to partially deburr a part. It is cheaper to do this in the machining cycle than to have an operator pick up, fixture, deburr, and verify that edge. In addition it eliminates the flow time associated with an extra deburr operation, it is controllable and it is independent of operator efficiency. Examples of this include brush deburring on screw machines and lathes, touching edges with sandpaper while a burr is still chucked on the lathe, and milling off a heavy roll over burr.

While it is not the intent of this paper to describe the capabilities of deburring processes a few comments are in order.

Selecting a deburring process cannot be done without some knowledge of the burr properties, piece part requirements, and the deburring process. Most processes will remove small burrs without noticeably affecting part tolerances. There are only a few processes, however, which can remove large burrs without affecting part tolerance. If money is not limited it is always possible to find a process which will remove any burr. In most shops, however, the only alternatives are to hand deburr or to vibratory deburr. In these cases the limitations of vibratory deburring and even hand deburring may dictate the machining process. In some cases a grinding, reaming, honing, or extra machining operation will be required for the sole purpose of producing a burr which can be removed. Thus for minimum cost parts, deburring and edge requirements may dictate the machining sequence used.

Despite the large number of companies involved in deburring there is very little data available by which to compare the various deburring processes. Thus at this time it is practically impossible to accurately determine which deburring process can be used most economically. If there is one single action which would reduce deburring costs the most, it would be the coordination, compilation, and publication of reliable data on deburring. This project alone could save industry several million dollars a year. Even with the meager data available today it is possible to construct a computer program which would select optimum deburring processes. For reliable use by many different industries, however, a bigger data base is needed than is currently available.

In summary there are four important rules to remember and 12 questions to answer on every part.

Rule #1 - If you don't make a burr, you don't have to remove it

Rule #2 - Every conventional machining operation produces some burr

Rule #3 - If you don't have to remove the burr, don't remove it

Rule #4 - The machining conditions affect the deburring costs

DEBURRING CHECK LIST

1. Does it have to be deburred?
2. Does it have to be deburred now?
3. What burr must be removed?
4. How much edge break is allowed (required)?
5. Does it have to be done by hand?
6. Will fixturing or hand tools help?

7. Can it be done on machine time
8. Can two deburring techniques be combined to minimize total deburring cost?
9. Will backup material make deburring more economical?
10. Can fixtures be designed with burr clearance?
11. How can the burr be minimized?
12. Can the part or process be redesigned to reduce deburring?

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FIGURE 1 : TAKE ADVANTAGE OF PART DESIGN TO MINIMIZE DEBURRING

FIGURE 2: IMPACT OF BURR LOCATION

SHOULDER RELIEF
(NOT FUNCTIONAL)

(a)

BURR CAN BE PLACED
AT a OR b BY PROPER
CHOICE OF MACHINING SEQUENCE

(b)

BURR PREVENTS ASSEMBLY
DEBURR IS REQUIRED

BURR IS CAPTURED IN ASSEMBLY
NO DEBURR REQUIRED

FIGURE 3 : IDENTIFY THE EDGES TO BE DEBURRED

CHAMFER MARK INDICATES EDGES TO BE DEBURRED AT THIS OPERATION

Code	Instruction
1	Deburr a break edge 0.015-0.025" R.
2	Deburr a break edge 0.005-0.010" R.
3	Deburr a break edge 0.005" max. R.
4	Deburr a break edge 0.002"/0.003" R.
5	Deburr a break edge 0.002" max. R.
11	Remove heavy burr only
12	Remove feather edge
13	Chamfer first and last thread

A	Burr knife
B	Wire brush
C	Nylon brush ^{to Al₂O₃} Aluminum stone
D	240 grit paper
E	Wire wheel ²³
G	File
J	Cratex "bullet"
S	Burr ball

FIGURE 4: SHOP INSTRUCTIONS ON EDGE REQUIREMENTS

BURR LOCATION

VIBRATORY DEBURRING OPERATIONS CAN BE EXPEDITED IF THE CUTOFF BURR IS LEFT ON THE ROUNDED END OF THIS SCREW MACHINE PART, RATHER THAN ON THE FLAT END.

FIGURE 6: PLACE THE BURR FOR EASIEST REMOVAL.

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Stamper

FIGURE 5: EFFECT OF CUTTER FEEDRATE ON TOTAL UNIT COST

FIGURE 7: IDENTIFY DESIRED BURR LOCATION
 UTILIZE BACKUP MATERIALS TO MINIMIZE BURRS

CROSS SECTION

TURN STEM AFTER MILLING FLATS
WIRE BRUSH ON LATHE TO REMOVE BURRS

ADVANTAGE

THIS SEQUENCE OF OPERATIONS MINIMIZES THE BURR
AND
DEBURRING IS PERFORMED AS PART OF TURNING OPERATION
(IT IS RAPID AND DOESN'T REQUIRE EXTRA SETUP OR HANDLING)

FIGURE 8 : EFFECT OF PROCESS ON DEBURRING